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ON NON-RESONANT PERTURBATION MEASUREMENTS *

A perturbation measurement technique has been developed at Stanford University which determines the phase and field strength at a point inside a microwave structure by measuring the reflection produced at the input port by a perturbing bead. The theoretical basis for the measurement is presented in this issue by C. Steele.[1] Some applications and experimental considerations of the technique are presented here.

A typical experimental setup is shown schematically in Figure 1. Since the quantity of interest is the change of reflection due to the perturbation, the slide-screw tuner is used to tune out reflections before inserting the bead. The difference of the crystal currents is proportional to $A^2 |\gamma| \cos \phi$, where A is the amplitude of the reference signal from the generator, γ is the reflection of the bead and ϕ is its phase. The phase of γ for each bead location is determined by setting the precision phase shifter to achieve a null signal and the reflection amplitude by measuring the maximum unbalance signal. For a dielectric bead, Steele shows that $\gamma = k E^2 \exp(2i\theta)/P_o$ where E and θ are the amplitude and the phase of the electric field at the bead and P_o is the input power. While the constant k is calculable for simple solids of revolution, it is often more convenient to calibrate a bead in a structure of known properties such as the uniform input waveguide to the test structure or a cavity consisting of a right circular cylinder.

As with any perturbation measurement, the perturbation must be small. The magnitude of the reflection coefficient must be much less than unity and the product of the propagation constant associated with any coordinate by the length of the bead along that coordinate must be much less than unity (i.e., the bead must be much smaller than a wavelength). Furthermore, to avoid image effects, the distance from the walls of the structure to the bead must be large compared with the bead dimensions.

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The technique is most useful in traveling-wave structure in which either (1) the structure is sufficiently irregular that the standing-wave pattern produced by resonating the structure masks the significant phase and field strength distributions, or (2) the loss is so high that the structure will not support a resonance of high Q-factor, well-separated from adjacent resonances.

One example of the first type was the measurement of fields in a high-power waveguide vacuum valve which was developed at Stanford Linear Accelerator Center. The technique was used by R. P. Borghi to measure the peak fields in the valve, thus determining the high power-handling capability.

Another example is the measurement of the symmetry properties of the couplers for the SLAC accelerator sections. Although the accelerator section itself has cylindrical symmetry, the power is fed into the coupler from a waveguide iris on one side. An electron passing through an accelerator section is given a transverse impulse proportional to the line integral along the electron path of the quantity $j\,\partial E_z / \partial x$, where the complex quantity E_z is the coupler field. The measurement of the phase was made by R. P. Borghi and G. A. Loew with a precision of about 0.1° using the technique described above. A transverse phase shift of about 1° was observed, which was large enough to require design changes in the SLAC accelerator.[2]

In waveguide two-ports, an additional useful measurement may be made. The perturbing bead may be represented as a shunt susceptance which introduces equal forward- and back-scattered waves in a running wave. The back-scattered wave is observed at the input; as shown by Steele', it is a measure of the square of the field, normalized to the input power. The forward-scattered wave is observed as a phase shift at the output; it is a measure of the square of the field intensity, normalized to the power flux at the bead.[3, 4] The ratio of the two is a measure of the attenuation from the input port to the bead.

The reflection and the transmitted phase-shift techniques were used by the authors to calibrate a mockup of the tapered disk-loaded bunching section of an X-band electron linear accelerator buncher.**

Measurement of the reflection from a perturbing bead allowed direct determination of the phase velocity and field strength on the axis of the structure. The ratio to the measurement of transmitted phase shift allowed a check of the predicted value of attenuation. Errors of phase velocity, field strength, and internal matching were disclosed in the calibration measurements of the mockup. Small corrections were computed and the final accelerator was constructed and re-measured.

Although the one-way loss of the final accelerator was 7 db, so that a resonance technique would have been meaningless, the final measurements were easily made to a precision of 3° in phase and 2% in amplitude.

The reflection measurement is now being used by R. P. Borghi as a final test after turning on all accelerator sections produced for SLAC (approximately 1000 ten-foot sections).

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** The phase velocity was to vary from 0.5 c to 1.0 c in the first five wavelengths of the structure. The field strength was to increase by a factor of 7 in the same distance.

References

1. C. Steele, "A Non-Resonant Perturbation Theory", (this issue)

2. see page 584, G. A. Loew & R. H. Helm, IEEE Trans. NS 12:580-92 (June 1965) "Beam Dynamics Problems in A High Energy Electron Linac".

3. G. Kino, "Normal Mode Theory in Perturbed Transmission Systems", Electronics Research Laboratory Report No. 84, Stanford University, Stanford, California (May 2, 1955).

4. R. P. Lagerstrom, "Interaction Impedance Measurements by Perturbation of Traveling Waves", Electronics Research Laboratory Report No. 7, Stanford University, Stanford, California (February 11, 1957).

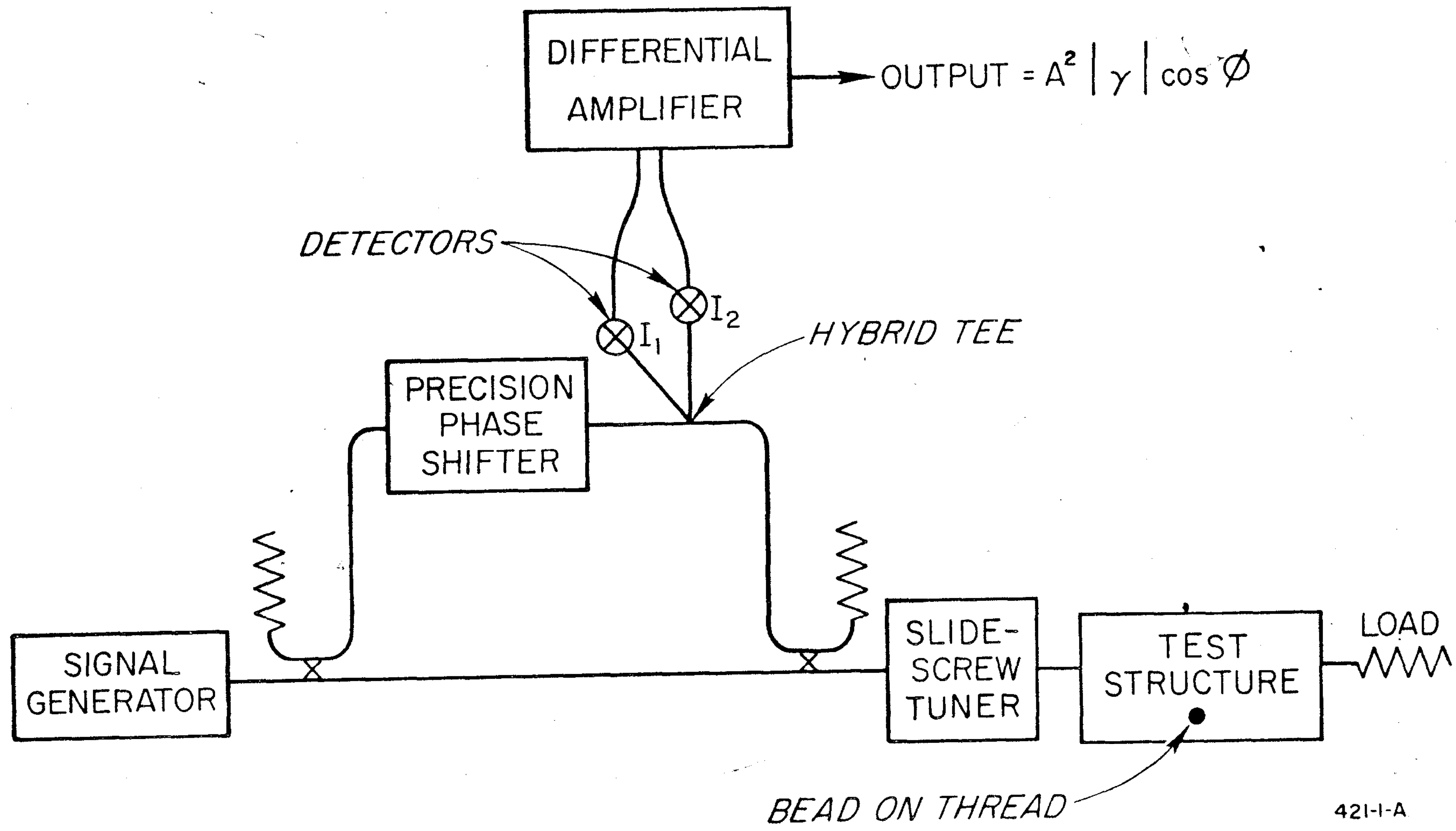

FIG. 1--REFLECTION PERTURBATION MEASUREMENT